# Effects of Exhaust Aftertreatment Technologies on Concentrations of Diesel Particulate Matter and Gases in Underground Mines

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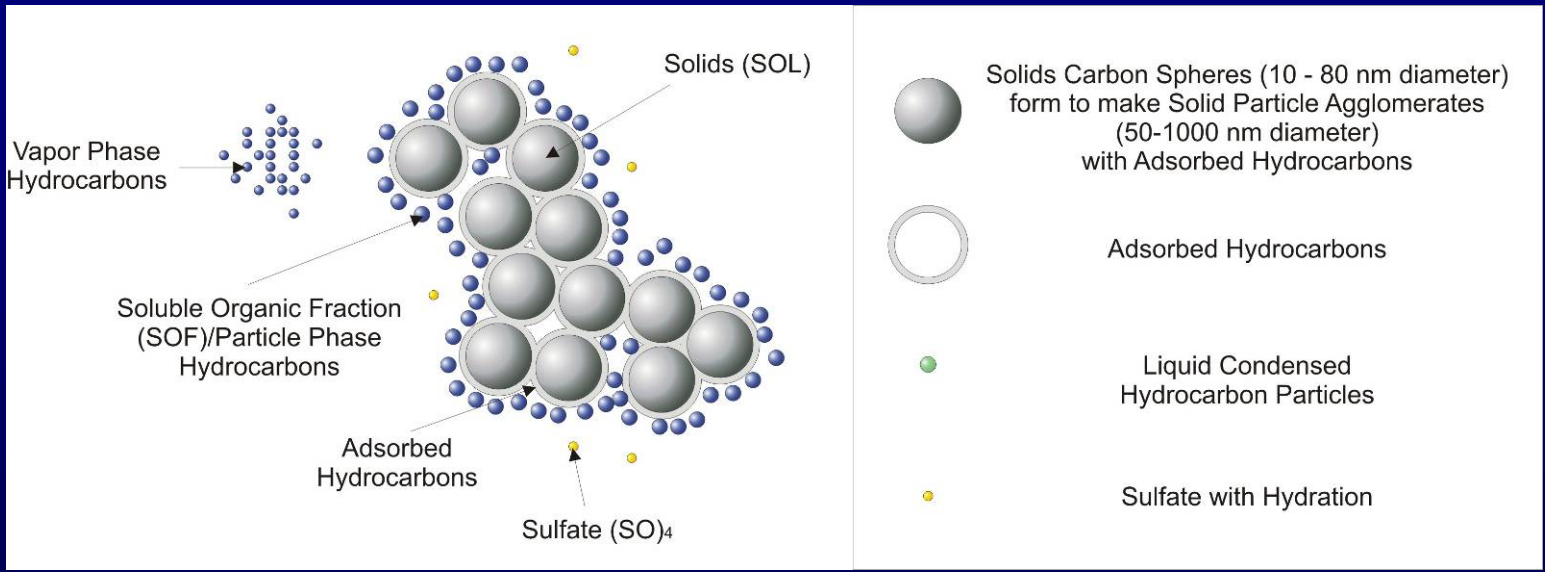
# Control of Diesel Emissions at their Source

- Engine-Out Emissions
  - Engine design
  - Maintenance
  - Alternative Fuels
- Aftertreatment Technologies

Achieving substantial reductions in the exposure to DPM depends on the ability of the industry to widely implement advanced diesel emissions control technologies primarily DPF systems.

# Diesel Emissions from Underground Mining Equipment

- Diesel particulate matter (DPM) and elemental carbon (EC)
- CO
- NO and $NO_2$
- $CO_2$
- hydrocarbons



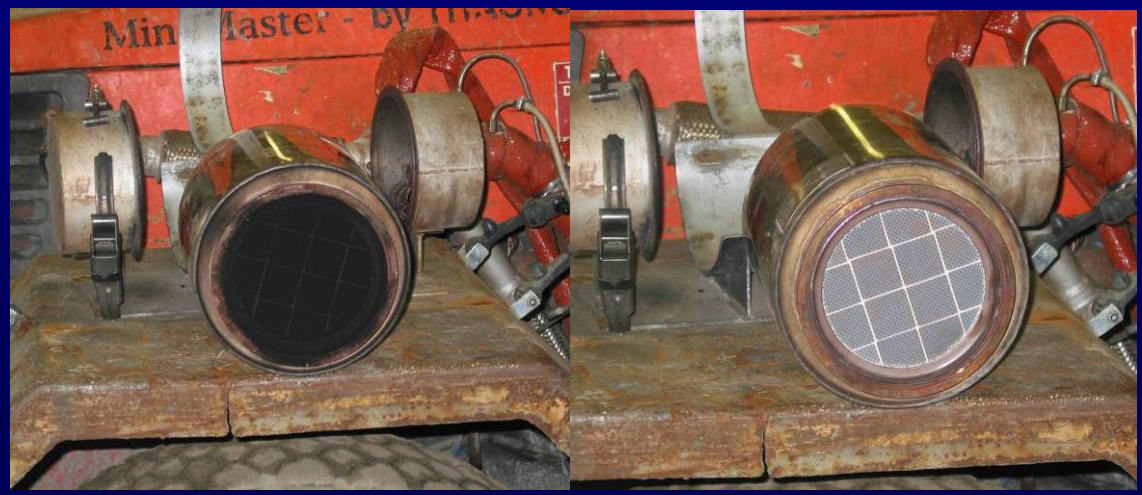
# Aftertreatment Technologies

- CO and hydrocarbons:
  - Diesel oxidation catalytic converters (DOC)
- Diesel particulate matter (DPM) and elemental carbon (EC):
  - Diesel particulate filter (DPF) systems;
  - Filtration systems (FS) with disposable filter elements (DPEs);
  - Flow through filters
- NO and $NO_2$
  - Lean $NO_x$ catalyst,
  - Selective catalytic reduction (SCR) systems
- Integrated aftertreatment systems

# Effects of DPF systems and DFEs of DPM emissions
## Verifications/Certifications

MSHA Verification (http://www.msha.gov/01-995/Coal/DPM-FilterEfflist.pdf):

| Filtration System | Efficiency (TDPM) |
|---|---|
| Cordierite DPF | 85% |
| Silicon carbide DPF | 87% |
| Sintered metal DPF | 80% |
| DFE | 80-83% |



# Effects of DPF systems and DFEs of DPM emissions
## Verifications/Certifications

### VERT Filter List
### ( www.dieselnet.com/tech/text/ch_filterliste.pdf )

| Filtration Rate | New | After 2000 hours |
|---|---|---|
| Particle Count (20-300 nm) | > 95% | > 95% |
| EC mass conc. | > 90% | > 90% |

### CARB Verification
### (http://www.arb.ca.gov/diesel/verdev/vt/vt.htm)

| Reduction | Classification |
|---|---|
| < 25% | Not verified |
| > 25% | Level 1 |
| > 50% | Level 2 |
| > 85%, or < 0.01 g/bhp-hr | Level 3 |

# Effects of DPF systems and DFEs of DPM emissions
## Verifications/Certifications

DEEP
(http://www.deep.org/research.html)

- Field evaluation of diesel particulate filter systems in an underground mine - INCO
- Field evaluation of diesel filter systems in an underground mine - Noranda Technology Centre

NIOSH (http://www.cdc.gov/niosh/mining/pubs/programareapubs8.htm

- Effectiveness of Selected Diesel Particulate Matter Control Technologies for Underground Mining Applications:
  - Isolated Zone Study, 2003 **2003**
  - Isolated Zone Study, 2004 **2004**

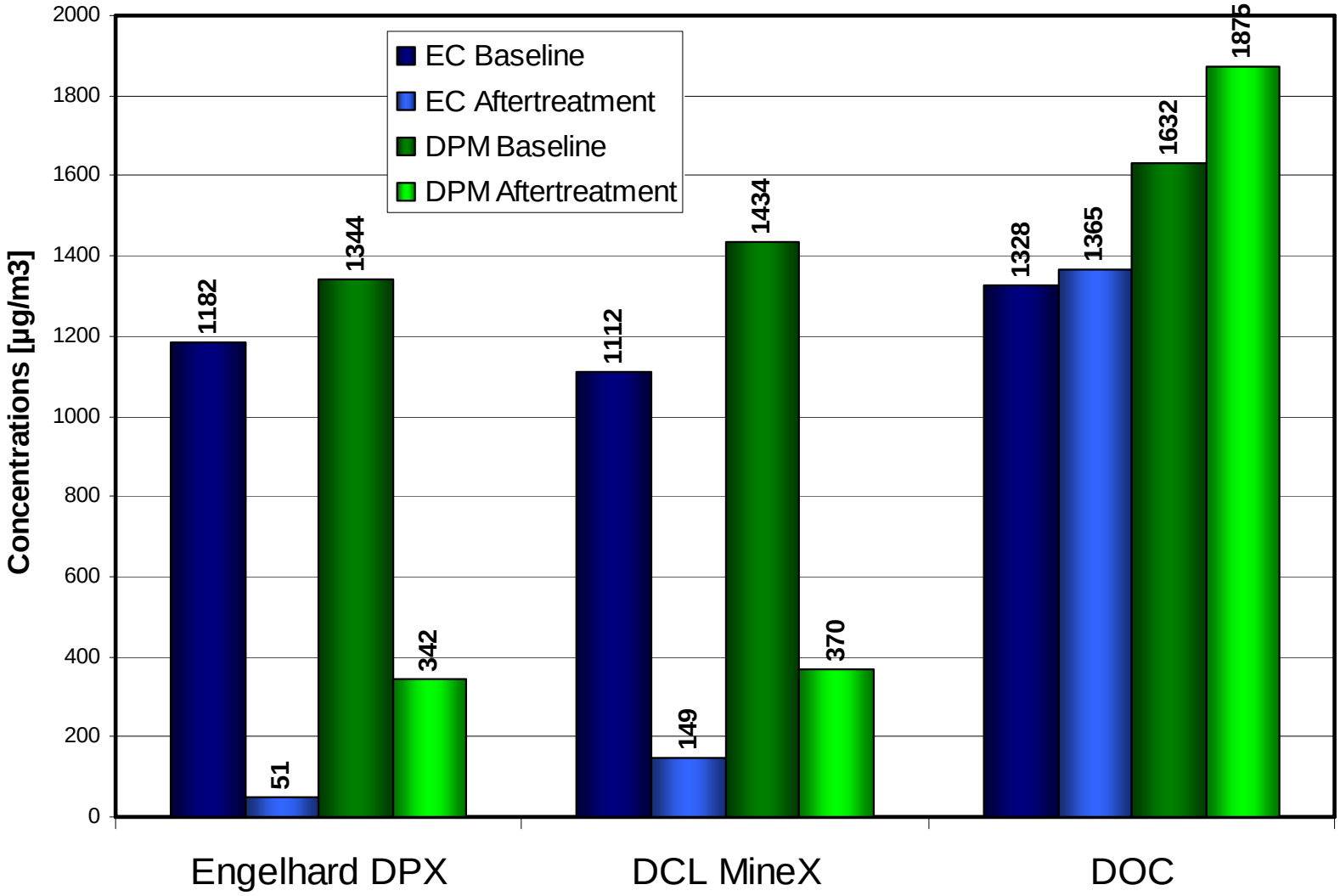
# Isolated Zone Studies

- The objective was to measure the effects of selected diesel emissions control technologies on the concentrations and properties of aerosols and gases in mine air.

- Evaluated Technologies
  - DPF systems;
  - DFEs;
  - DOCs and;
  - Reformulated fuels.

# The Effects of DPFs and DOC on Mass Concentrations of Elemental Carbon (EC)

2003



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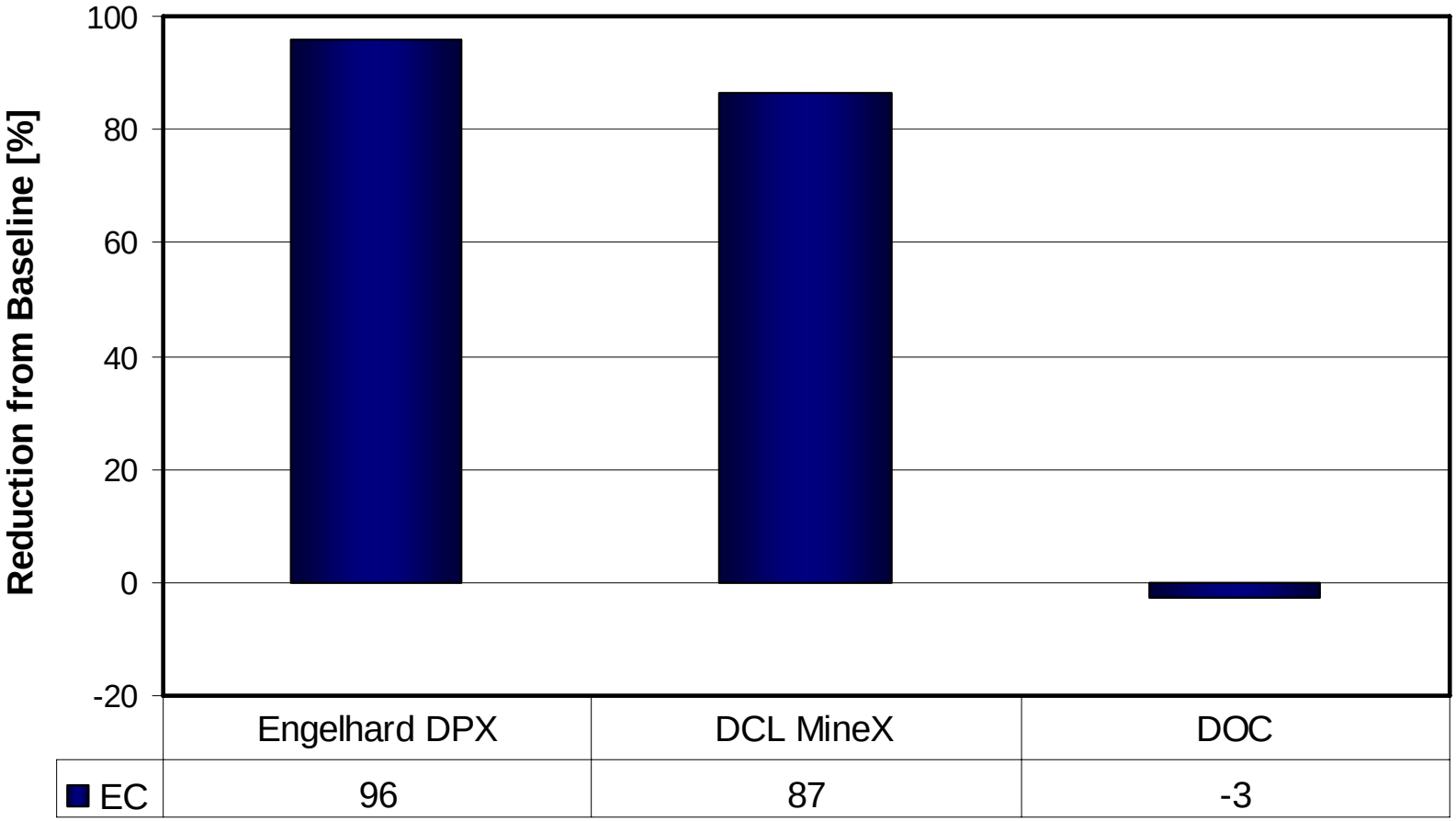
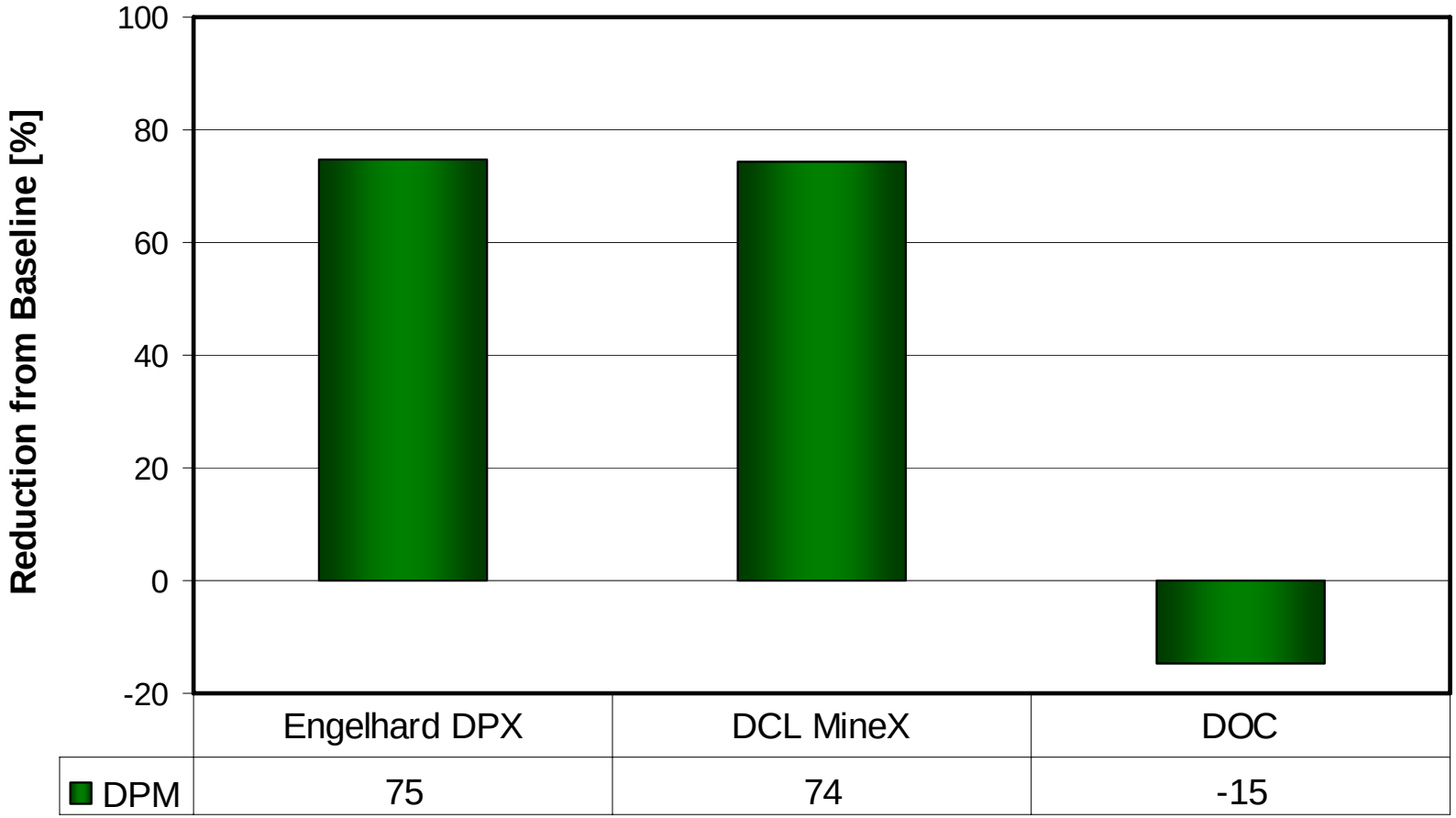


# The Effects of DPFs and DOC on Mass Concentrations of Total Diesel Particulate Matter (DPM)

2003



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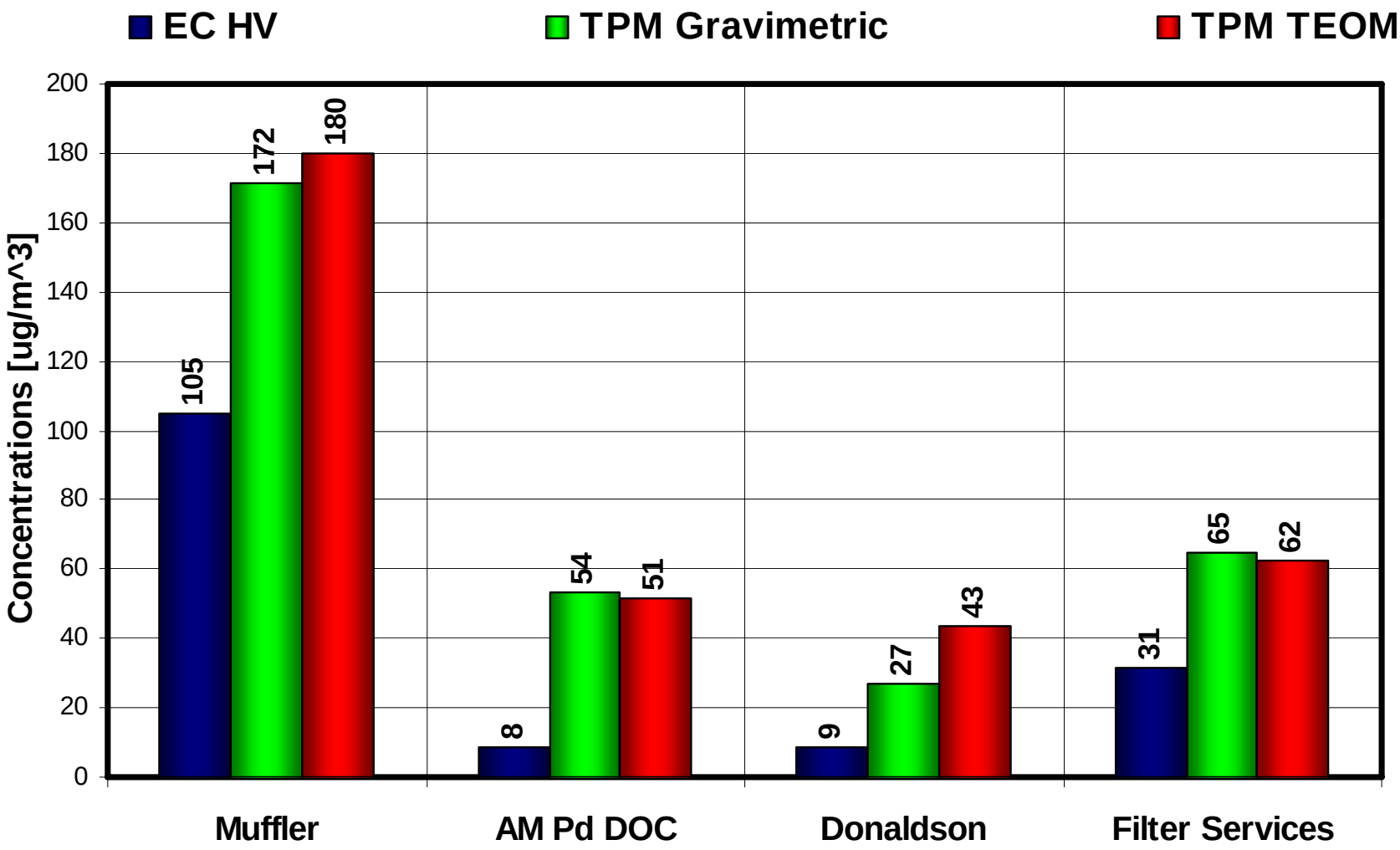
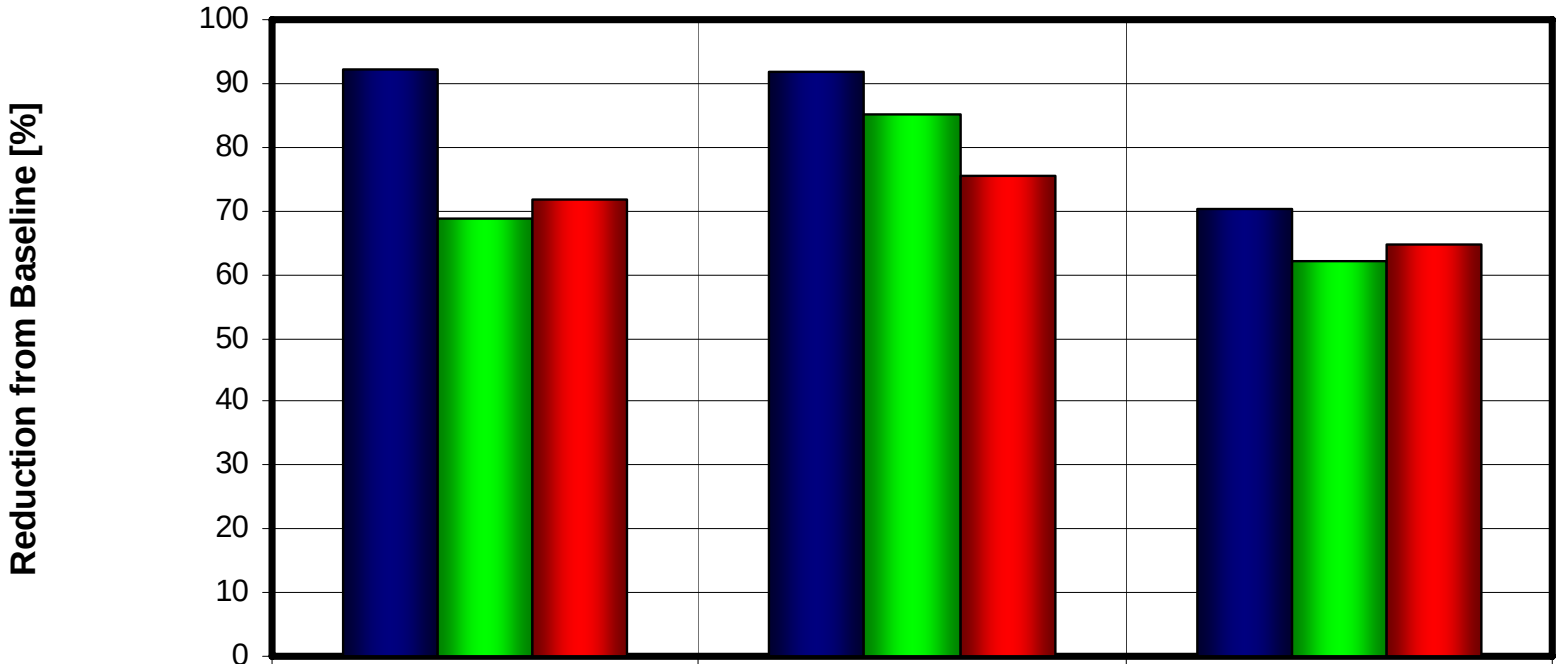
2004



# The Effects of DPFs and DFEs on Mass Concentrations of Elemental Carbon (EC)

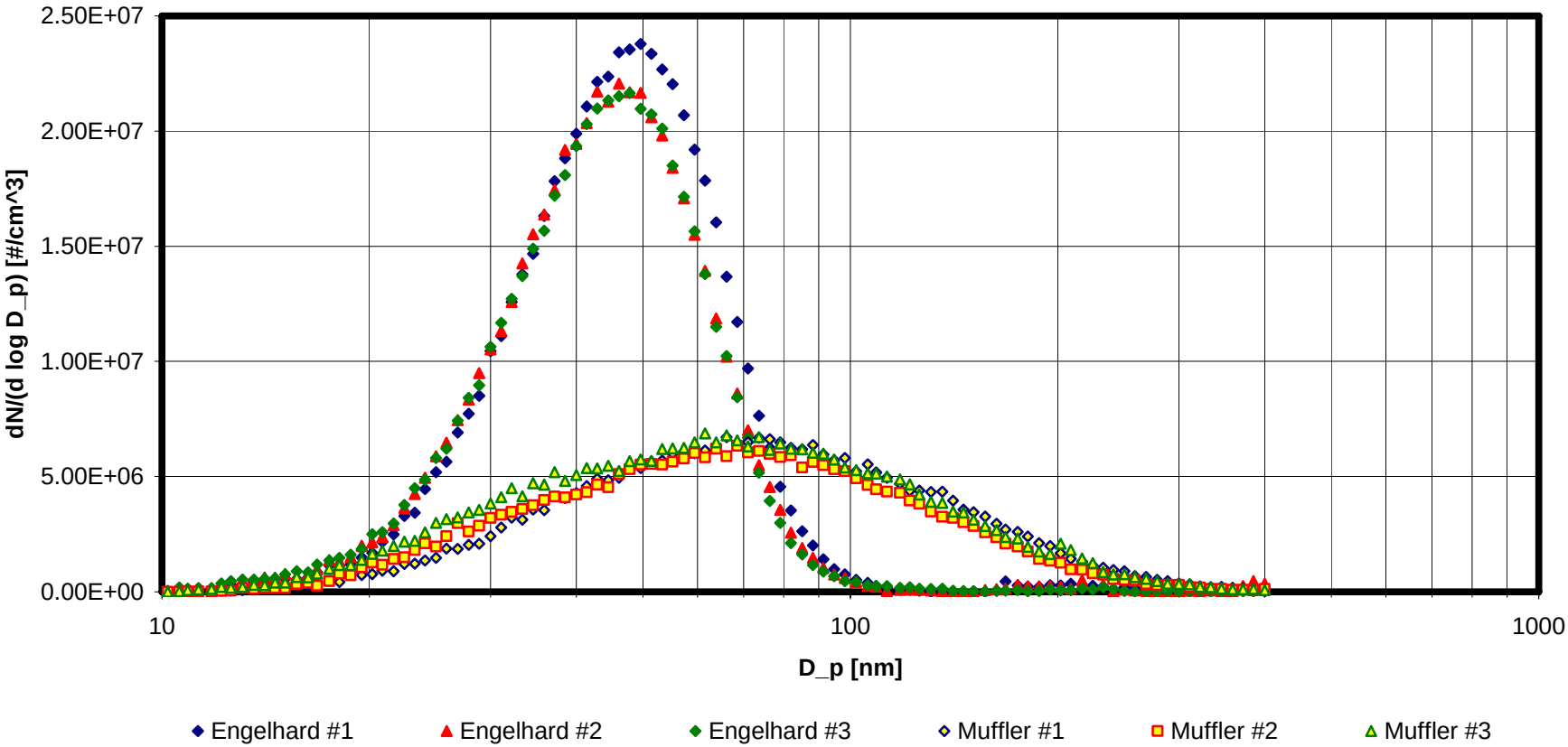
**2004**




| | AM Pd DOC | Donaldson | Filter Services |
|---|---|---|---|
| EC HV | 92 | 92 | 70 |
| TPM GRAV | 69 | 85 | 62 |
| TPM TEOM | 72 | 76 | 65 |

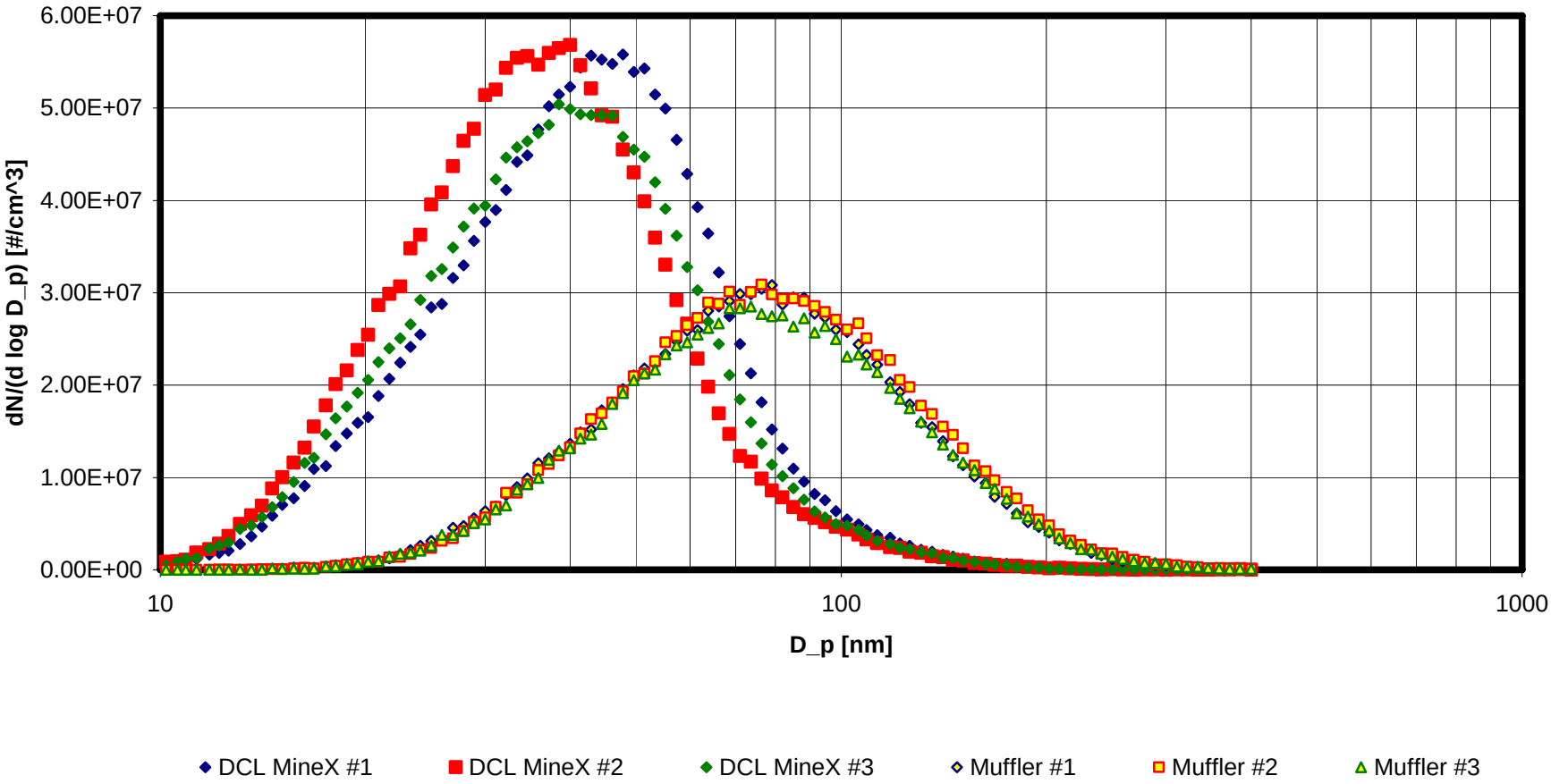
# Size distribution of aerosols in mine air
## Truck with Engelhard DPX DPF vs. Muffler

**2003**



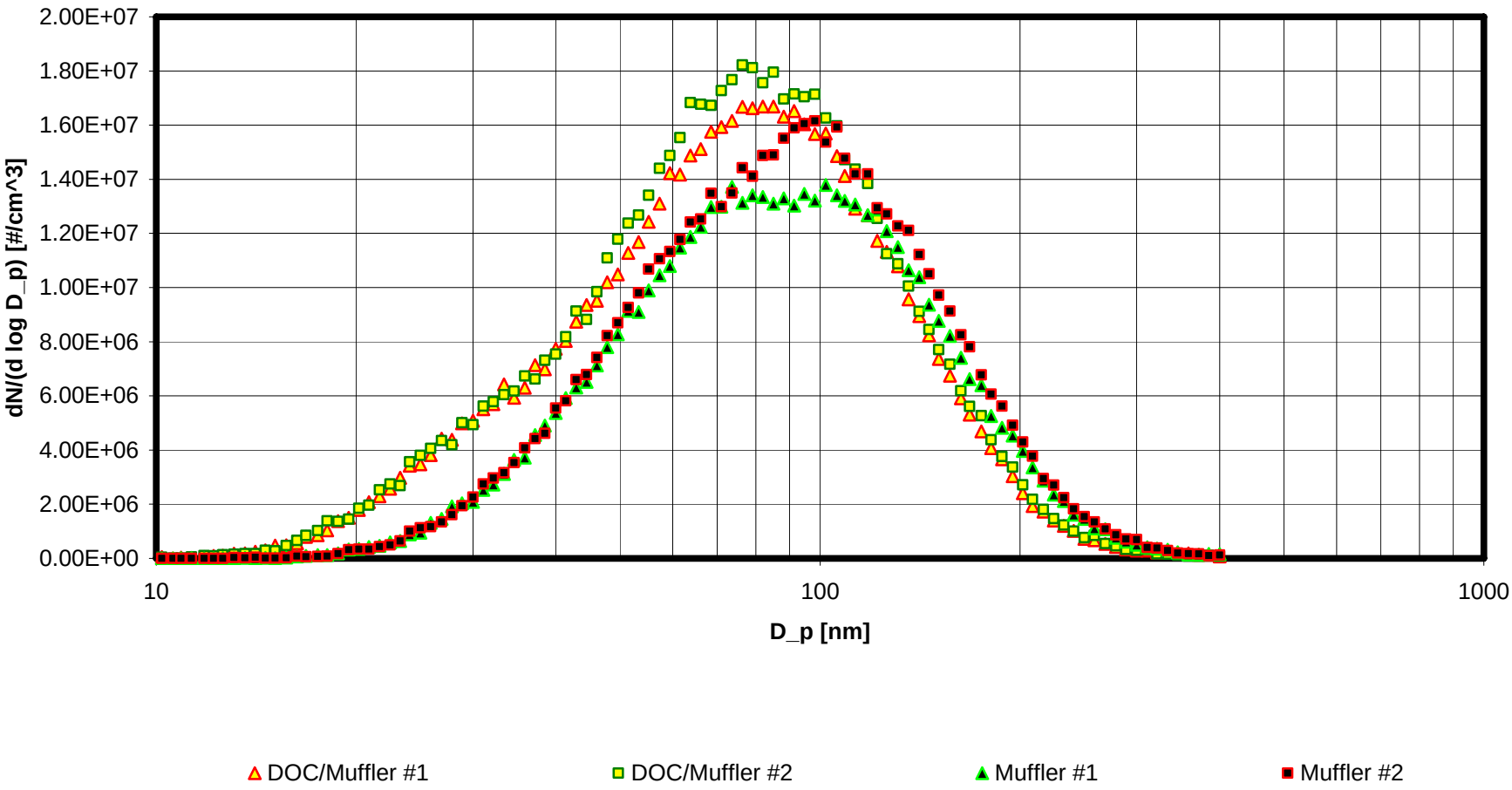
# Size distribution of aerosols in mine air
## LHD with DCL MineX vs. Muffler

**2003**



# Size distribution of aerosols in mine air
## LHD with DOC/Muffler vs. Muffler

**2003**



# Tested DPFs Greatly Increased the Particulate Number Concentrations

2003

| Aftertreatment | Increase in Total Particulate Conc. [%] |
|---|---|
| Engelhard DPX DPF | 79.6 |
| DCL MineX DPF | 60.6 |
| Engelhard PTX DOC | 18.2 |

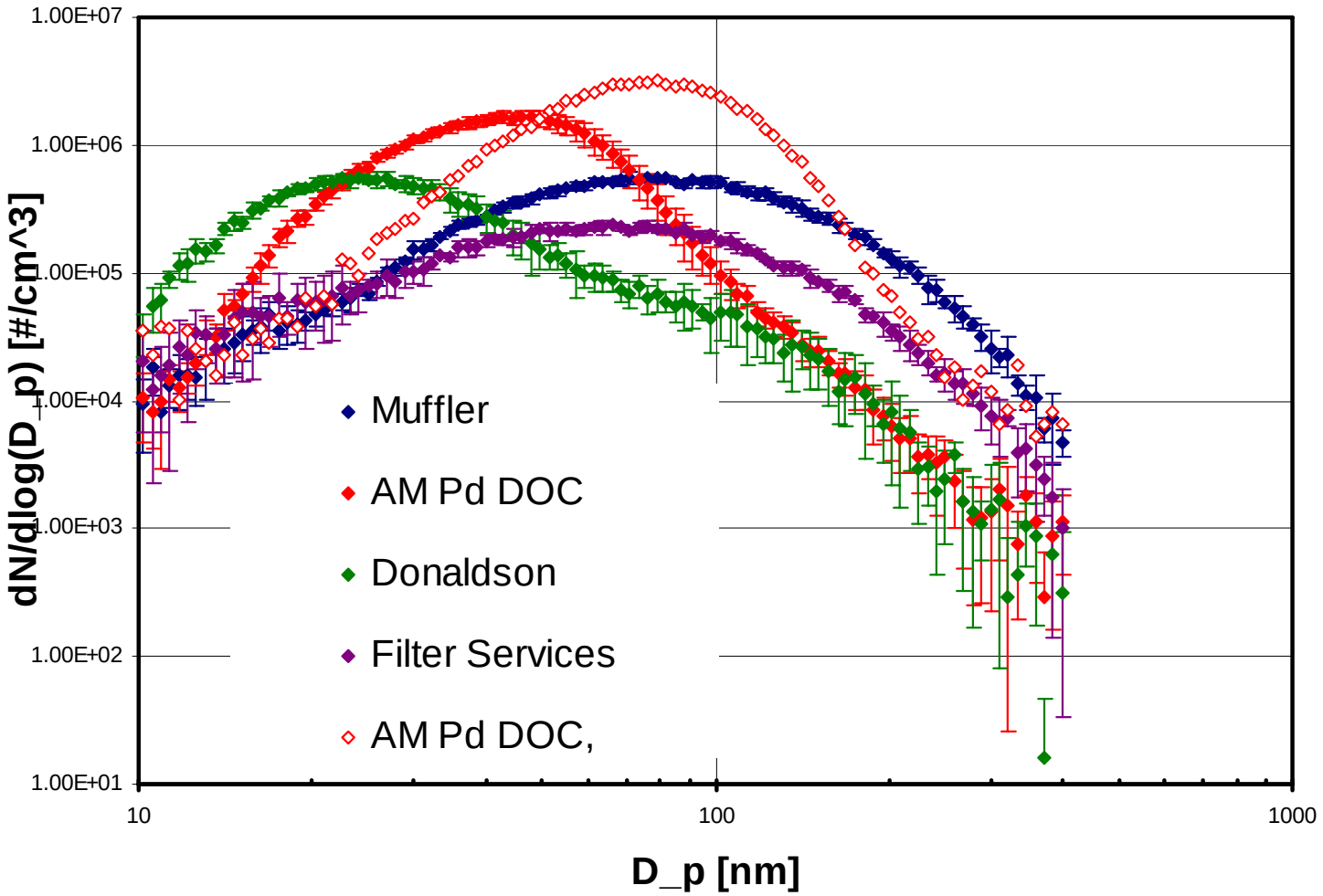
# Tested DPFs and DOC Reduced Particle Size (Average Geometric Mean)

2003

| Aftertreatment | Average Geometric Mean [nm] | |
|---|---|---|
| | Baseline | Aftertreatment |
| Engelhard DPX DPF | 67.3 | 43.7 |
| DCL MineX DPF | 75.4 | 38.1 |
| Engelhard PTX DOC | 85.7 | 72.4 |

# The Effects of DPFs and DFEs on Concentrations of Aerosols with Electrical Mobility Diameter Between 10 and 392 nm in Mine Air

2004



# Tested DPF Greatly Increased the Particulate Number Concentrations while Tested DFEs Reduced Particulate Number Concentrations

| Aftertreatment | Change in Total Particulate Conc. [%] |
|---|---|
| AM DPF with Pd DOC | **105.2** |
| Donaldson DFE | **-26.1** |
| Filter Services DFE | **-53.5** |

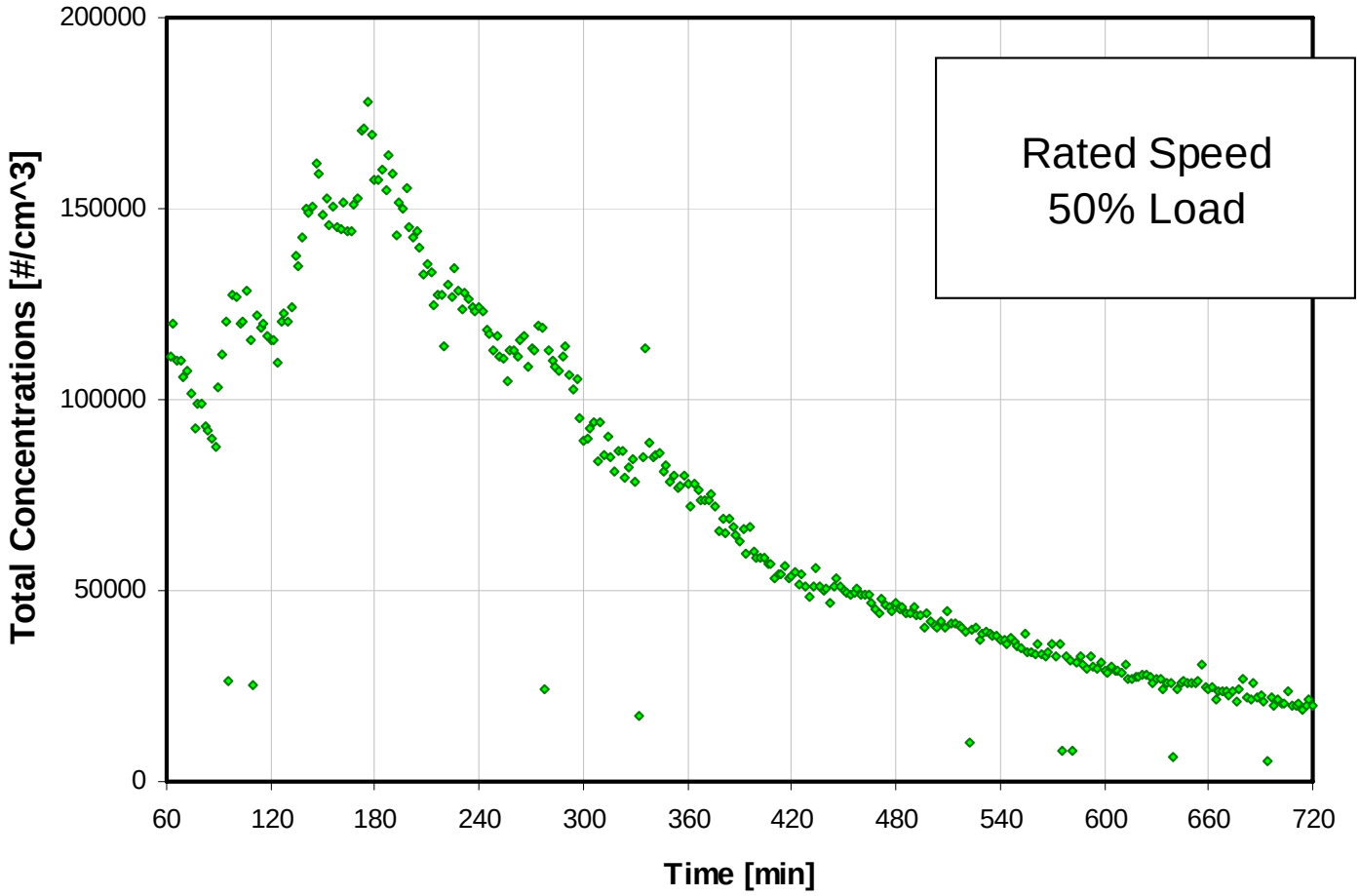
**2004**

# Tested DPFs Reduced Particle Size (Average Geometric Mean)

**2004**

| Aftertreatment | Average Geometric Mean [nm] | |
|---|---|---|
| | Baseline | Aftertreatment |
| AM DPF with Pd DOC | 34.2/86.0 | 42.5 |
| Donaldson DFE | | 24.2/68.3 |
| Filter Services DFE | | 35.8/73.6 |

# The Effectiveness of DFEs increase with DPM load



# Secondary emissions of $NO_2$ can result in higher ventilation rate requirements

| Dilution Ratios | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MODE | Engine-out Emissions | | | | | DPF-out Emissions | | | | |
| | $CO_2$ | CO | NO | $NO_2$ | PM | $CO_2$ | CO | NO | $NO_2$ | PM |
| | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 16.3 | 0.9 | 25.5 | 13.0 | 65.4 | 15.7 | 0.4 | 22.8 | 33.4 | 6.9 |
| 2 | 14.3 | 1.0 | 18.4 | 11.5 | 46.2 | 13.9 | 0.3 | 14.2 | 37.6 | 5.2 |
| 3 | 11.5 | 1.3 | 14.8 | 14.2 | 48.3 | 11.7 | 0.3 | 8.0 | 52.3 | 5.6 |
| 4 | 5.7 | 4.0 | 16.8 | 33.2 | 27.0 | 5.5 | 0.3 | 9.7 | 13.8 | --- |
| 5 | 20.5 | 1.8 | 43.3 | 16.5 | 72.0 | 19.9 | 0.4 | 36.2 | 28.5 | 9.9 |
| 6 | 18.7 | 1.5 | 32.6 | 13.1 | 72.7 | 18.3 | 0.3 | 26.2 | 36.9 | 3.5 |
| 7 | 15.9 | 1.6 | 26.8 | 15.1 | 56.5 | 15.9 | 0.3 | 19.1 | 52.3 | 3.6 |
| 8 | 2.3 | 2.1 | 7.6 | 17.4 | 20.1 | 1.9 | 1.8 | 8.3 | 7.2 | --- |

# The ambient concentrations of $NO_2$ increased when vehicles with platinum coated DPFs were tested

**2003**

| Aftertreatment | Increase in $NO_2$ Conc. [%] |
|---|---|
| Engelhard DPX DPF | **269** |
| DCL MineX DPF | **180** |
| Engelhard PTX DOC | **26** |

# Change in DOC catalyst formulation from Pt to Pd eliminated increase in Nitrogen Dioxide ($NO_2$) concentrations

**2004**

| Aftertreatment | Increase in $NO_2$ by control technology |
|---|---|
| | % |
| AM Pt DOC | 180 |
| AM Pd DOC | -2 |

# DFEs decreased concentrations of Nitrogen Dioxide ($NO_2$) in mine air

2004

| Aftertreatment | Decrease in $NO_2$ by control technology |
|---|---|
| | % |
| Donaldson DFE | 44 |
| Filter Service DFE | 87 |

# Parameters that Affects Effectiveness and Performance of DPF system

- In-use vs. certification emissions
- Operation outside of design parameters
- Exhaust system integrity
  - Internal leaks
  - External leaks

# Parameters that Affects Effectiveness and Performance of DPF system Other Sources of Emissions

- Installation
- Engine and aftertreatment maintenance

## Other Sources of Emissions

- Crank case breather

# Design, selection, and implementation of DPF systems for underground mining presents unique challenge

- Occupational exposure regulations
- Wide variety of application with specific operational, engineering and maintenance issues
- Retrofit systems vs. OEM
- Small market
- "Business as usual" philosophy vs. reality

# Thank you for your attention!

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